Impact by an Orthogonal Metal Grid upon Differential- and Common-Mode Characteristics of Coupled Lines in PCB Technology Structures.

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Abstract

This paper deals with a rigorous study of the impact by perpendicular metal grids on the characteristics of microstrip and coplanar coupled transmission lines. An electromagnetic analysis shows the variations of the propagation parameters in common and differential modes for each type of lines, in the presence of a metal grid. As transmission zeroes are liable to occur at certain frequencies, in particular in the common mode, we investigated the part played by the most influential grid parameters on these disturbances.

Introduction

Higher integration densities in PCB (Printed Circuit Board) structures as well as the use of new concepts such as "System in Package" (SiP), are both at the origin of a significant rise in the number of possible interactions between various interconnects or between interconnects and power/ground grids. Increase in clock frequencies makes these interactions more problematic for signal integrity [1].

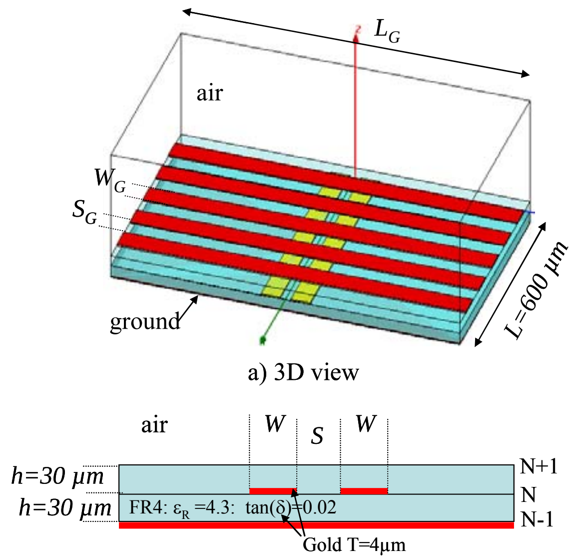
Effects induced by metal grids on the interconnect characteristics in a multilayered architecture were evidenced in [2][3]. Here, focus is on the impact by perpendicular metal grids of two coupled lines. The microstrip and coplanar structures under study are introduced at first. Then, the analysis method is briefly presented prior to showing how the propagation parameters, in the common and differential modes, are affected by the density of a metal grid.

Moreover, as such grids may generate electromagnetic disturbances, especially the occurrence of transmission zeroes in the common mode, these investigations were carried out to gain more insight into the influence by grid-length and grid-density.

Structures and Analysis Methods

The PCB structures under study consisted of either two microstrip coupled lines or two coplanar ones. Fig. 1 shows the microstrip PCB multilayer structure, whereas Fig. 2 presents the coplanar PCB multilayer structure. One should note that, in both cases, the length and width of the coupled lines are $L = 600\ \mu m$ and $W = 55\ \mu m$, respectively.

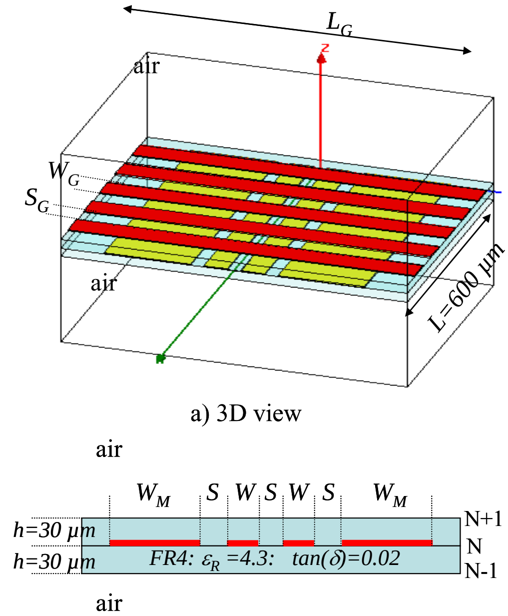
Moreover, the coupled lines are placed at the level of metallization denoted by N with a spacing, $S = 30\ \mu m$, between them. They are inserted between two 30-µm-thick FR4-type substrates ($\varepsilon_R = 4.3$ *and* $tg(\delta) = 0.02$). The conductors (coupled lines, grid, ground plane) are all made of gold (Au) with a 4-µm-thick metallization layer (T). The metal grid is set on the upper level of metallization (N + 1) at right angle to the signal lines and consists of 5 identical and interconnected lines.



a) 3D view

b) Transverse cut

Fig. 1: Microstrip coupled-line structure with an orthogonal metal grid set at the upper level. (*$L = 600\ \mu m$, $W = 55\ \mu m$, $S = 30\ \mu m$* and *$h = 30\ \mu m$*).



a) 3D view

b) Transverse cut

Fig. 2: coupled-line structure with an orthogonal metal grid set at the upper level (*$L = 600\ \mu m$, $W = 55\ \mu m$, $S = 30\ \mu m$, $W_M = 200\ \mu m$*, and *$h = 30\ \mu m$*).

In the microstrip structure presented in Fig. 1, the metallization level denoted by N - 1 is the ground plane.

In the coplanar structure presented in Fig. 2, the two "signal" lines are surrounded by two ground lines of width $W_M = 200\ \mu m$ set at the N level at a distance $S = 30\ \mu m$ from them. On the other hand, there is no ground plane at the N-1 level.

For both structures, the metal grid density (D) is defined by Eq.(1),

$$D\% = 100 \frac{W_G}{(W_G + S_G)} \qquad (1)$$

where W_G is the width of the grid lines and S_G is their spacing.

The 3-D electromagnetic simulation tool based on a finite element code, HFSS ®, was used to simulate both structures at frequencies from 1 to 50 GHz and for different density values. The terminal mode was used to get the generalized S-parameters. The boundaries surrounding the two structures are perfect electrical short circuits (PECs), and in the microstrip structure the interconnected lines of the metal grid were also linked to the lower ground plane. By using the formulas available in [4] to convert the generalized S-parameters to modal S-parameters (common or even modes and differential or odd modes), one can easily determine the propagation characteristics of both modes, or their RLCG per-unit-length (p.u.l.) parameters.

Grid's influence on propagation characteristics

Fig. 3 (microstrip structure) and Fig. 5 (coplanar structure) illustrate the evolutions of the characteristic impedance (in modulus) and phase factor of the two structures versus the grid density in both modes and at the frequency, $F = 25$ GHz.

Fig. 3 shows that the characteristic impedance and phase factor in the common mode are more affected by the upper metal grid than those in the differential mode. This is in agreement with the electromagnetic field configuration in both modes [5]. It is worth noting that, in both modes, the characteristic impedance is linearly decreasing with the grid density, which corresponds to an increase in per-unit-length capacity and a decrease in per-unit-length inductance.

On the other hand, the increase of the phase factor with the grid density reflects the rise of the effective permittivity and, therefore, the greater electromagnetic field concentration around the signal conductors.

Fig. 4 illustrates the variations in electromagnetic field concentration at two grid densities, 20 and 80% and at the frequency, F = 25 GHz. Fig. 4a (common mode) and Fig. 4b (differential mode) both show that, at the higher density, the field is more confined in the dielectric substrate than at the lower density value.

About the coplanar structure, Fig.5 shows that, in both modes, the increase in grid density causes a decrease of impedance. It reflects the increase of the p.u.l. capacitance per and the decrease of the equivalent p.u.l. inductance.

As observed for the microstrip structure, in both modes the phase factor is increasing with the grid density, which explains the concentration of the electromagnetic field around the signal conductors.

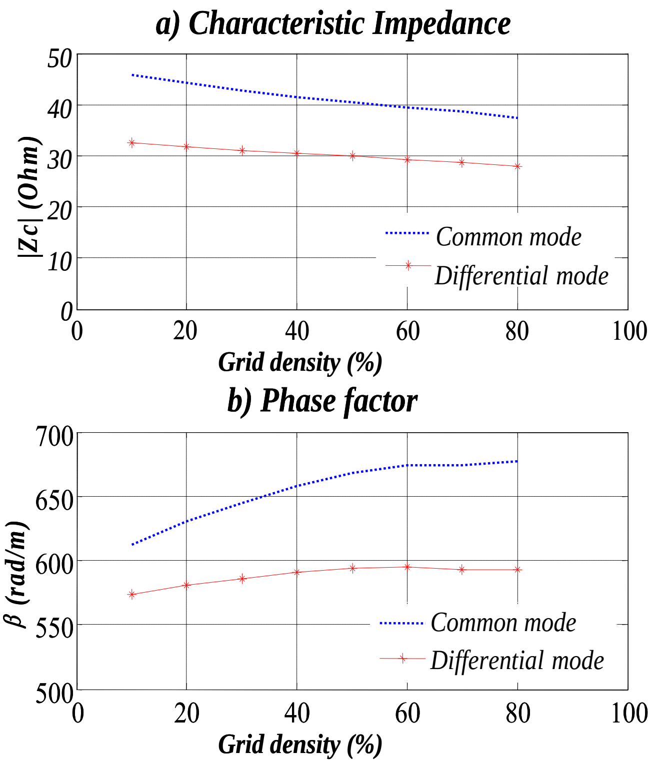


Fig. 3: Characteristic impedance (a) and phase factor (b) of Microstrip structure lines versus grid densitiy. (*F = 25 GHz*).

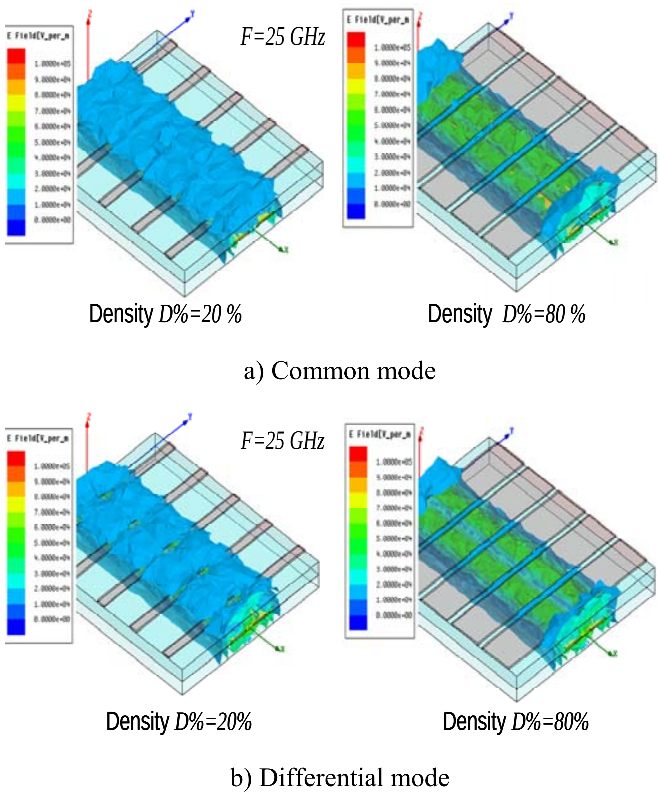


Fig. 4: Electric field magnitude for common (a) and differential (b) modes, in the microstrip structure at two grid densities (20 and 80%).

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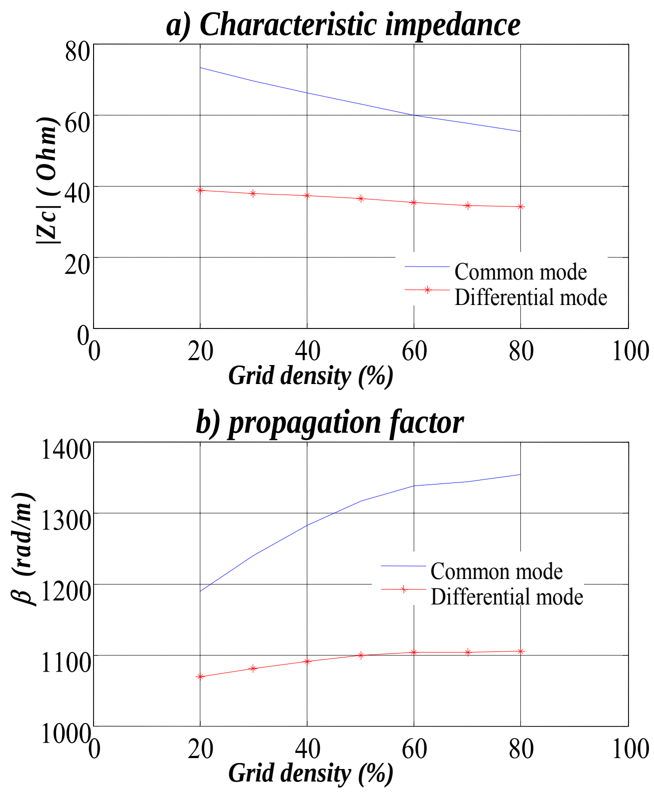
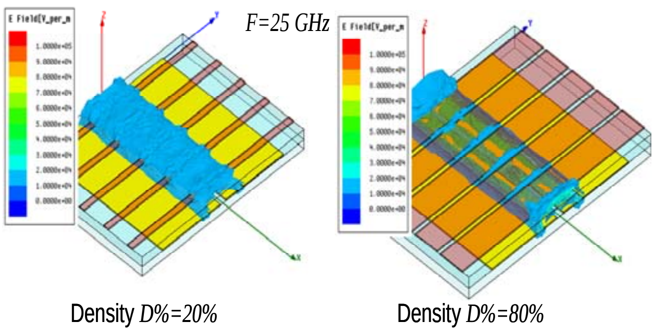
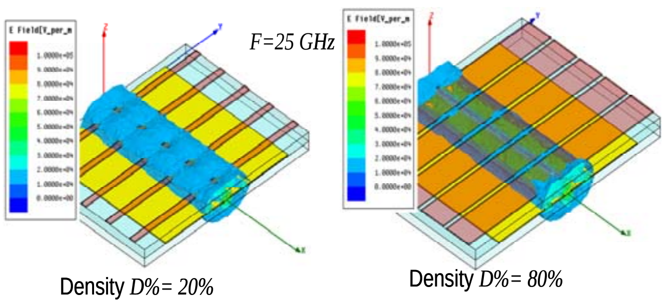


Fig. 5: Characteristic impedance (a) and phase factor (b) of the coplanar coupled-lines structures versus grid density (*F = 25 GHz*).



a) Common mode.



b) Differential mode

Fig. 6: Electric field magnitude for common (a) and differential (b) modes, in the coplanar structure at two grid densities (20 and 80%).

However, it is worth noting that, with the coplanar structure, the characteristic impedance and the phase factor are more affected by the presence of the grid in the common mode than in the differential mode. Once again, this difference is explained by the electromagnetic field concentration in the coplanar line surrounding-substrate. Fig. 6 evidences the greater electric field containment at the higher density (80%) in both modes.

Effect by Grid Length upon Propagation Parameters.

To determine the impact by the grid length upon the propagation parameters, especially the transmission coefficient, "S_{21}", simulations were run in both modes. The grid density was set at 50% and the grid length (L_G) was varied from 2 to 3.5 mm. Fig. 7 deals with the microstrip coupled-line structure. It clearly shows the occurrence of a transmission zero in the common mode conversely to the differential mode, which seems unaffected. This can be explained by the fact that the electromagnetic field configurations associated to the common mode are similar to those of microstrip line. Indeed, with a single microstrip line, an orthogonal metal grid is liable to make appear transmissions zeroes [2]. Moreover, the electromagnetic field associated to the differential mode is concentrated between the two signal conductors, so the coupling with the metal grid is very low and there is no anti-resonant phenomenon.

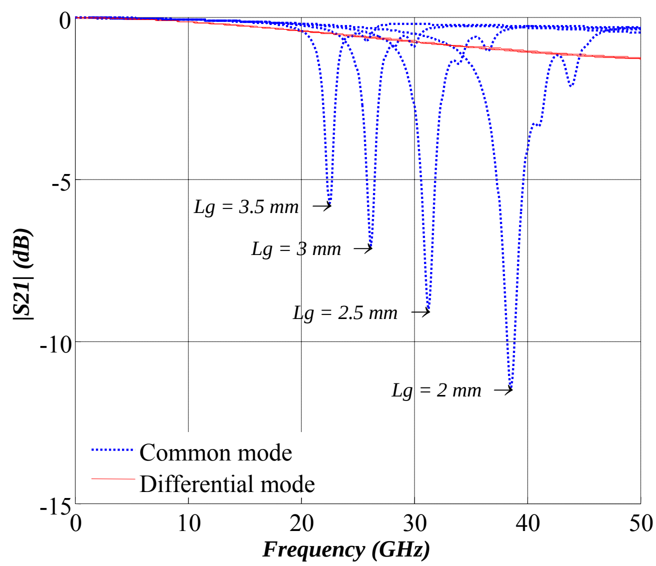


Fig. 7: Microstrip Structure: S_{21} parameter for a 50% grid density and different "L_G" grid lengths.

One should note on Fig. 8 that the frequency at which transmission zeroes occur is inversely proportional to the grid length indeed, the longer the grid is, the lower the frequency is. It is also worth noticing (Fig. 8) that, in the common mode, the grid density has only a secondary effect on the value of transmission zero occurrence frequency.

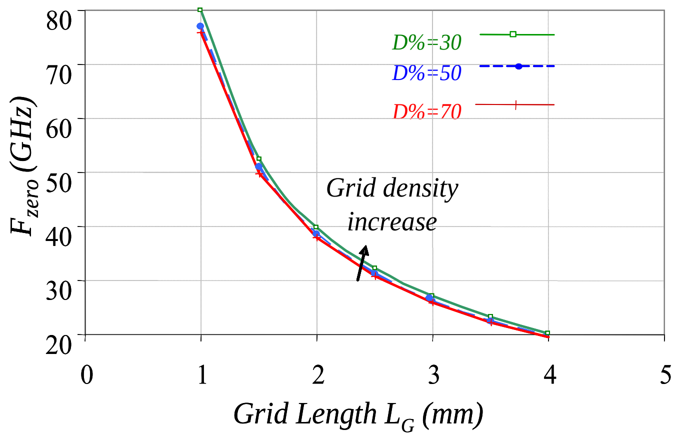


Fig. 8: Microstrip structures. Initial transmission zeroe frequency versus the grid length at three densities (30, 50 and 70%).

For the coplanar structure, Fig. 9 highlights the existence of disturbances induced by a long grid in the common mode. For the differential mode, the transmission coefficient is unaffected by the grid length. It can be explained by the difference of electromagnetic field configuration in the common and differential modes. The coupling between the electromagnetic field and the grid is greater in the common mode than in the differential one. The value of the transmission zero frequency is directly related to the inverse of the grid length.

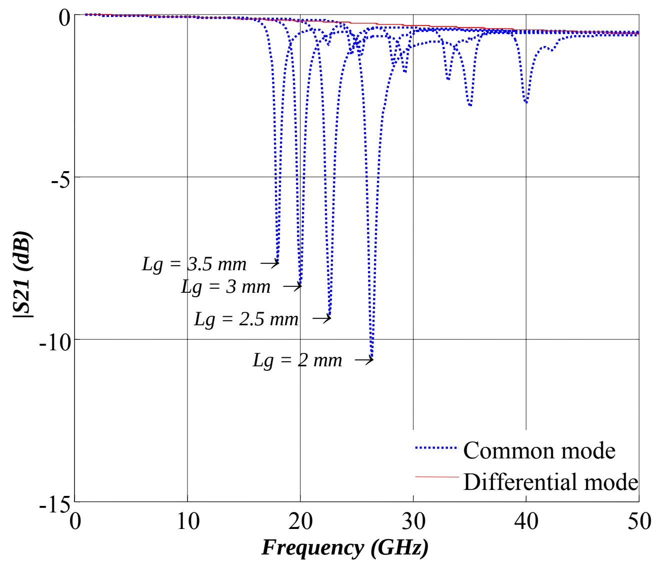


Fig. 9: Coplanar Structure: S_{21} parameters for a 50% grid density and different "L_G" grid length.

Conclusions

This paper described how a metal grid perpendicular to the microstrip, or coplanar, coupled lines of PCB structures affects their characteristics. It showed that the grid caused changes in the even- and odd-mode propagation parameters of both structures. Moreover, when the grids are particularly long, they can cause the occurrence of transmission zeros, mainly in the common mode. The results obtained about both structures proved to be quite similar.

References

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